EVALUATION OF MARINE AND FRESHWATER GROWTH AND SURVIVAL OF AUKE CREEK COHO SALMON

By

Joshua R. Russell, B.S.

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Approved:

David Tallmon, Committee Co-Chair
Megan McPhee, Committee Co-Chair
Milo Adkison, Committee Member
Scott Vulstek, Committee Member
Milo Adkison, Chair
Department of Fisheries
S. Bradley Moran, Dean
College of Fisheries and Ocean Sciences
Michael Castellini, *Dean of the Graduate School*

Abstract

Coho Salmon (*Oncorhynchus kisutch*) are a species of great social and economic importance for commercial, sport, personal-use, and traditional harvest. We explored factors influencing Auke Creek Coho Salmon smolt production, growth, and marine survival. We analyzed 35 years (1980-2014) of data collected at the Auke Creek Research Station weir in Juneau, Alaska. This extensive data series allowed for an analysis of Auke Creek Coho Salmon growth and survival that is not possible elsewhere. Creek flow best explained variation in smolt-per-adult production. Analysis of freshwater and saltwater scale growth zones failed to identify a specific growth zone with a significant influence on marine survival. Marine survival had a positive relationship with the magnitude of regional hatchery releases and the Pacific Decadal Oscillation. Changes in climate and hatchery production could have negative effects on survival of Auke Creek Coho Salmon, as evidenced by low returns in recent years associated with anomalously high temperatures in the Gulf of Alaska. The impact of climate change and increased hatchery production should be considered in future management decisions.

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1 - Introduction

Coho Salmon *Oncorhynchus kisutch* is a species of economic and cultural value across its range (Beier et al. 2008; Fall et al. 2014). In Southeast Alaska, Coho Salmon are harvested in commercial, sport, and traditional fisheries (Shaul et al. 2011; Fall et al. 2014). Changes in salmon growth and survival can have direct impacts from the cultural level (reduced opportunities to practice customary and traditional harvest) to the region-wide economic level. It is important to understand how environmental and anthropogenic changes affect Coho Salmon survival and how their growth is changing over time.

Marine survival of Coho Salmon may be determined by a size-selective process upon early marine entry (Beamish et al. 2004; Farley et al. 2007). During this period, mortality is high due to physiological changes in osmoregulation and the intense predation pressure faced by smaller juveniles. Reduced early marine growth has been associated with increased early marine mortality in Coho Salmon (Beamish et al. 2004). In contrast, Beacham et al. (2017) found no effect of size on early marine survival of age 1.0 (European age designation system) Coho Salmon. These studies show care must be taken when inferring size-selective mortality from scale growth as it is often difficult to be sure the same adult and juvenile populations are being sampled in these larger studies (Beacham et al. 2018).

The relative importance of freshwater and marine growth to marine survival has not received much study in Coho Salmon, even though they spend a large amount of their life cycle in freshwater (Lawson et al. 2004). Primary productivity and the abundance of hatchery and wild juvenile salmon have also been shown to have a strong influence on Coho Salmon marine survival (Briscoe et al. 2005; LaCroix et al. 2009; Andres Araujo et al. 2013), and previous work suggests that much of the variation in marine survival of Auke Creek Coho Salmon happens during early marine life (Briscoe et al. 2005). The ability to quantify this variation will allow for insights into the early marine environment and allow for better management decisions.

Marine and freshwater growth is likely affected by a large number of abiotic and biotic factors, making it difficult to identify the processes causing changes in growth. Studies have emphasized the importance of smolt size and early marine growth and their effects on marine survival (Holtby et al. 1990; Beamish et al. 2004). Both growth and size can be strongly influenced by oceanic conditions, whereas freshwater survival of juvenile salmon can be influenced by winter climate, inferred from air temperatures and stream discharge (Nickelson 1986; Lawson et al. 2004; Sparks et al. 2018). Consequently, our ability to predict salmon productivity can be improved by understanding the combinations of factors that determine juvenile salmon growth and survival.

Within the Auke Creek watershed, and more broadly across Southeast Alaska, numerous factors influence Coho Salmon growth (Robins 2006; Malick et al. 2009). While the combined effects of all these factors upon growth can be difficult to quantify, their net effects can be estimated by measuring scale growth. The growth (in length) of a fish can be inferred from the number and width of the circuli of the scale. These circuli are laid down sequentially over time and the patterns among the circuli can be used as a proxy for the overall growth of the fish and to provide insights into variability in growth among years (Fukuwaka and Kaeriyama 1997; Fisher and Pearcy 2005).

This thesis examines the relative influence of freshwater versus marine growth on the survival of Auke Creek Coho Salmon using a retrospective, scale-based analysis of growth. Scale growth of Auke Creek Coho Salmon can be divided into three distinct periods: freshwater year 1 (FW1), freshwater year 2 (FW2), and salt water year 1 (SW1). These zones were selected because Auke Creek Coho Salmon spend 1-2 years in freshwater before ocean entry. They then spend 1 year in the marine environment before returning to spawn. The one exception is the ‘jack’ life history, an alternative reproductive tactic, for males that spend only a single summer in the marine environment before returning to spawn (Gross 1991). Previous studies have highlighted ongoing changes in some characteristics of the Auke Creek Coho Salmon population, including changes in age structure, length, migration timing, and migration duration (Kovach et al. 2013; Lewis et al. 2015; Malick et al. 2015; Russell et al. 2018), but growth patterns of Auke Creek Coho Salmon have not been fully investigated. Understanding the connections between variations in environmental conditions, growth, and survival will help inform management decisions in the face of potentially changing stock-recruit relationships as a result of changes in freshwater production and marine survival.

There are a number of reasons why Auke Creek Coho Salmon are uniquely worthy of intensive study. First, the permanent weir on the creek makes it possible to capture nearly all migrating Coho Salmon, both leaving the system as smolts and returning as adults. This enables more accurate and precise estimates of freshwater and marine survival than can be obtained elsewhere. In addition, Auke Creek Coho Salmon are an Alaska Department of Fish and Game indicator stock where virtually all smolts are enumerated and tagged with coded wire tags (CWT), so how the Auke Creek stock responds to biotic and abiotic factors is of direct management interest and influences regional management decisions. The recovery of these coded wire tags in commercial and sport fisheries yields precise estimates of marine survival not available for other populations of Coho Salmon in Southeast Alaska. Furthermore, this watershed is currently experiencing rapid warming and increased temperature variability, a phenomenon that is seen in much of Southeast Alaska (Shanley et al. 2015), so this represents an opportunity to gain insights into factors that may influence salmon in other Southeast Alaska streams where high quality, multidecadal time series do not exist.

The specific objectives of our study were to: 1) identify what environmental factors influence freshwater smolt production; 2) examine the impacts of freshwater and marine scale growth on marine survival; and 3) determine what environmental and biological factors have influenced marine survival of Auke Creek Coho Salmon over more than three decades (1980-2014).

2 - Methods

2.1 Study Site

The National Oceanic and Atmospheric Administration's (NOAA) Auke Creek Research Station has a permanent weir that has been in full-time operation since 1980, located 16 km northwest of downtown Juneau, Alaska (Figure 1). Species captured and counted at the weir each year include Coho Salmon, Sockeye Salmon *O. nerka*, Chinook Salmon *O. tshawytscha*, Pink Salmon *O. gorbuscha*, Chum Salmon *O. keta*, Cutthroat Trout *O. clarkii*, and Dolly Varden *Salvelinus malma*.

Data have been collected using the same protocols every year (Vulstek et al. unpubl.). A daily census is taken of all upstream and downstream migrants. A subset of all downstream migrants are sampled for age, length, and weight, and a subset of all upstream migrants are sampled for age and length.

2.2 Freshwater Survival

Auke Creek Coho Salmon Smolts/Adult Production - A time series of Coho Salmon smolt and adult abundance was available from brood year 1980-2013. We expressed freshwater survival as the number of smolts per adult on a brood-year basis. Mixed-age smolts were assigned to a brood year using age composition estimates from juvenile scales. The smolt/adult ratio was analyzed to capture possible density-dependent effects.

2.3 Marine Survival

Auke Creek Coho Salmon Marine Survival - Coho Salmon marine survival for saltwater entry years 1980-2013 was inferred from coded wire tagging of all emigrant smolts and the complete counting of all immigrant adults. Using CWT individuals caught in the sport and commercial fisheries, the Alaska Department of Fish and Game (ADF&G) calculates an expansion factor that we used to estimate the total number of Auke Creek Coho Salmon caught in the fisheries (Bernard and Clark 1996). Because complete smolt and adult counts are made at the Auke Creek weir, the harvest expansion was the only estimate involved in the calculation of marine survival. This provides precise estimates of marine survival for each smolt release year.

2.4 Scale Growth

Auke Creek Coho Salmon Scale Collection - Coho Salmon growth was inferred from scales sampled annually from 1980 to 2014 (Vulstek et al. unpubl.). This dataset includes paired mid-eye to fork length and scale samples for males and females throughout the annual run of returning adults. The sampling procedure for these fish remained unchanged over the course of the time series and involves taking four preferred scales per fish. Each preferred scale was taken from a region of the fish's left side, along an imaginary line drawn from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin, and from approximately two rows of scales above the lateral line (Major et al. 1972; Hagen et al. 2001). Four scales were taken per fish because of potential damage, regeneration, and/or reabsorption, which could cause inaccurate scale age and growth estimates. These scales were placed on gum cards for temporary storage and acetate impression cards were created for long-term storage.

Imaging Process - Acetate cards were used to create digital images following a procedure adapted from Hagen et al. (2001). Acetate cards were scanned on an ALOS Z-Scan 46-II microfiche scanner with a Minolta Type 3 22-50x lenses and Fiche Carrier #5, and imaged at 30x magnification. The images were then digitized in Image-Pro with a scale analysis macro created by the Alaska Department of Fish and Game (D. Oxman, ADF&G, unpubl). Digital marks were placed on the outermost edge of the two possible freshwater annuli (FW1 and FW2, respectively), and at the outermost edge of the scale (SW1, representing marine growth). Growth zones were measured between the focus of the scale and the annuli marks (Figure 2). A yearly average of each growth zone was used for analysis.

2.5 Environmental and Biological Variables - Freshwater Survival

All variables for freshwater survival analysis are summarized in Table 1 and described in more detail below.

Auke Creek Temperature - Daily temperatures in Auke Creek are available across the time series. Temperature was recorded using an in-creek logger (ONSET HOBO 4-Channel Analog Data Logger) located approximately 30 meters upstream of the weir structure. We hypothesized a negative relationship between creek temperature and freshwater survival because warmer creek temperatures have been associated with reduced survival due to their direct effects on migration timing, habitat conditions, and food availability during juvenile rearing (Lawson et al. 2004). A yearly average of daily March-July temperatures was used for analysis.

Air Temperature - Daily air temperatures were obtained from the NOAA Climate Data Online Database (https://www.ncdc.noaa.gov/cdo-web/), for the NOAA Auke Bay Station (Station ID:USC00500464) which is located 200 m from the Auke Creek Research Station. We hypothesized a negative relationship between air temperature and freshwater survival because air temperature is negatively correlated with Chinook Salmon smolt production in Southeast Alaska (Graham 2016), and these two species have similar ecologies. A yearly average of January-March daily air temperatures was analyzed.

Creek Flow - Gauge height served as a proxy for Auke Creek flow. Measurements were taken from a staff gauge below the weir for 2006-2013. For 1980-2005, a model was built for predicting gauge height based upon temperature and precipitation at Auke Creek (Bell et al. 2017). Although higher creek flow might mean more rearing habitat for Coho Salmon (Smoker 1955), scouring events during incubation can decrease production (Lawson et al. 2004). Additionally, increased flow can increase downstream movement in Coho Salmon (Giannico and Healey 1998), which can reduce survival by forcing fish into sub-optimal habitat. Additionally, juvenile Coho Salmon are visual feeders and increased flow and water turbidity would complicate feeding attempts (Berg and Northcote 1985). Consequently, we hypothesized that creek flow would affect smolt production, but we did not predict whether the correlation would be positive or negative. To match conditions during emergence from the gravel, and the earliest period Coho Salmon are present in the water column, a late spring - early summer (April-Jun) average of gauge height was obtained.

Ice Out - Ice out, defined as the spring date at which less than 50% of Auke Lake's surface is covered by ice, served as a proxy for the length of the growing season in Auke Lake

(Kovach et al. 2014). We hypothesized a positive relationship between ice out and smolt production as a later ice-out date is indicative of a longer freshwater growing season.

Median Migration Date - Median migration date is the date on which 50% of the migrating smolts have passed through the weir and entered the marine environment. Variation in this marine entry timing has been observed in Auke Creek (Kovach et al. 2013). We expected to see a negative relationship between median migration date and smolt production as a later migration period could be indicative of a missed optimal time of migration.

Year - Year was included as a random effect for our freshwater survival analysis. This random effect could account for variation in smolt/adult production not captured by our chosen explanatory variables.

<u>2.6 Environmental and Biological Variables - Marine Survival</u>

All variables for marine survival analysis are summarized in Table 2 and described in more detail below.

Auke Creek Coho Salmon Juvenile Length - Mean length at salt-water entry, obtained from measuring outmigrating smolts at the weir, was used as an explanatory variable for marine survival. Because our data were summarized as mean length by smolt age, a weighted average was calculated. This weighted average was calculated as follows for ocean entry year:

$$Mean\ Length = \frac{(age\ 1\ length * age\ 1\ counts) + (age\ 2\ length * age\ 2\ counts)}{age\ 1\ counts + age\ 2\ counts}$$

Length at salt-water entry affects Coho Salmon marine survival (Holtby et al. 1990; Lum 2003), which is consistent with the idea that size-based mortality strongly influences the early marine survival of juvenile salmon (Beamish and Mahnken 2001).

Southeast Alaska Hatchery Pink Salmon & Chum Salmon Index - An ADF&G database (https://mtalab.adfg.alaska.gov/CWT/Reports/default.aspx) provides the total number of yearly releases of hatchery Pink Salmon and Chum Salmon in Southeast Alaska. Released fishes can serve as one of the many food sources for juvenile migrating salmonids and may increase juvenile Coho Salmon growth (Parker 1971; Landingham et al. 1998; Mortensen et al. 2000). It is also possible that hatchery-released individuals of larger size provide a predation buffer by being an alternate food source for Coho Salmon predators (LaCroix et al. 2009). This hatchery index was positively correlated with Auke Creek Coho Salmon survival in previous studies (Briscoe et al. 2005; Robins 2006; Malick et al. 2009).

Year - Year has been included as a random effect for our marine survival analysis. This random effect could account for variation in marine survival production not captured by our chosen explanatory variables.

Pacific Decadal Oscillation (PDO) - PDO data are available from NOAA's Gulf of Alaska PDO index database (https://www.ncdc.noaa.gov/teleconnections/pdo/). PDO is a measurement of long-term temperature trends that persist for multiple decades over the mid-latitudes in the Pacific basin north of 20°N. A high PDO indicates warmer ocean conditions and increased productivity in the waters inhabited by Auke Creek Coho Salmon, but is associated with reduced early marine growth and survival of salmon in regions south of northern Southeast Alaska (Mantua et al. 1997). An average first marine winter (Nov-Jan) PDO was used for analysis.

North Pacific Index (NPI) - Yearly NPI data are available from the NOAA Climate Prediction Center database for the East Pacific - North Pacific Index (http://www.cpc.ncep.noaa.gov/ data/teledoc/ep.shtml). NPI is a measure of the Aleutian low-pressure zone and is defined as the area-weighted sea-level pressure. The NPI is expected to have a negative relationship with marine growth because low values indicate low-pressure systems in the Gulf of Alaska, which increase food availability to salmon during early marine life (Mundy 2005; Malick et al. 2009). An average first marine winter (Nov-Jan) NPI was used for analysis.

North Pacific Gyre Oscillation (NPGO) - The NPGO is a climate index that measures variability in the North Pacific Gyres circulation and is significantly correlated with fluctuations of salinity, nutrients, and chlorophyll-a in the Gulf of Alaska (Di Lorenzo et al. 2008). NPGO has positive effects on salmon productivity (Malick et al. 2016). An average first marine winter (Nov-Jan) NPGO was used for analysis.

Auke Creek Temperature - Auke Creek temperature was used as a proxy for local nearshore sea surface temperature (SST). Due to the location of temperature collection and the hydrology of Auke Creek, the temperature in the creek and SST in Auke Bay are highly correlated (Pearson's r = 0.94; Bell et al. 2017). SST has a positive relationship with growth and early marine survival of Auke Creek Coho Salmon (Briscoe et al. 2005; Malick et al. 2009). An average creek temperature during juvenile migration to saltwater (May-July) was used for analysis.

2.7 Statistical Analysis

Freshwater Survival vs. Environmental Conditions - All analyses were performed using R 3.6.0 (R Core Team 2019). The response term of smolts/adult was $\log_{10}$ transformed for normality. An initial full model for smolt production was fit as follows:

$$log_{10}(\frac{smolt}{adult}) = \beta_0 + \beta_1 ctemp + \beta_2 atemp + \beta_3 gauge + \beta_4 iceout + \beta_5 mmd + year + \varepsilon$$

During model preparation, strong, significant collinearity was identified between creek temperature (*ctemp*), air temperature (*atemp*), and ice out. Subsequently, creek temperature and air temperature were removed from the model giving a reduced form including gauge height, ice-out date, and median migration date (*mmd*):

$$log_{10}(\frac{smolt}{adult}) = \beta_0 + \beta_1 gauge + \beta_2 iceout + \beta_3 mmd + year + \varepsilon$$

Initial model fitting was explored within a linear mixed-effects framework fit by maximum likelihood. AICc scores were used to select a final, reduced model from candidate models consisting of all possible combinations of explanatory variables. Model assumptions of multicollinearity, normality, and variance were assessed, and no violations were found. Final model parameters were fit with restricted maximum likelihood.

Marine Survival vs. Growth - Yearly marine survival was used as the response variable, and yearly average growths in each growth zone were applied as explanatory variables. Yearly average zone growth was averaged from a subset of 25 males and 25 females from each year (Robins 2006). These zones were: first year freshwater (FW1) growth, second year freshwater (FW2), and first year saltwater (SW1). The response term of marine survival was $\log_{10}$ transformed for normality. An initial full model for marine survival using scale growth was fit as follows, with year as a random effect:

$$log_{10}(Marine\ Survival) = \beta_0 + \beta_1 FW1 + \beta_2 FW2 + \beta_3 SW1 + year + \varepsilon$$

Model fitting, selection, and verification proceed as previously described.

Marine Survival vs. Environmental Conditions - The response term of marine survival was $\log_{10}$ transformed for normality. An initial full model for marine survival was fit as follows with year as a random effect:

$$log_{10}(Marine\ Survival) = \beta_0 + \beta_1 js.length + \beta_2 hpc + \beta_3 pdo + \beta_4 npi + \beta_5 npgo + year + \varepsilon$$

Possible candidate models were restricted to only one large-scale oceanographic index (PDO/NPI/NPGO) per model to avoid overfitting. Model fitting, selection, and verification then proceed as previously described.

3 - Results

3.1 Freshwater Survival vs. Environmental Conditions

For freshwater survival using all combinations of explanatory variables, 8 candidate models were considered and the model with the strongest support included only a negative relationship with gauge height ($R^2 = 0.15$, LogLik = 9.83, Weight = 0.47, Figure 3, Table 3).

$$log_{10}(\frac{smolt}{adult}) = 15.17 - 0.66gauge + year + \varepsilon$$

In addition to having the lowest AICc, no other model had a *Δ*AICc less than 2, thus strengthening its support as the best model. The random effect of year showed no trends (R^2 Marginal = 0.14, R^2 Conditional = 0.89).

3.2 Marine Survival vs. Growth

For modeling the relationship between scale growth and marine survival, using all combinations of explanatory variables, 8 candidate models were considered. The model with the lowest AICc showed a negative relationship with FW2 growth; however, it was within a *Δ*AICc of 2 of the null model (Figure 4, Table 4).

$$log_{10}(Marine\ Survival) = -0.27 - 0.95FW2 + year + \varepsilon$$

The random effect of year showed no trends (R^2 Marginal = 0.12, R^2 Conditional = 0.89).

3.2 Marine Survival vs. Environmental Conditions

For marine survival, using our restricted combinations of explanatory variables, 32 candidate models were considered and the model with the strongest support included positive relationships with both hatchery releases and PDO (R^2 = 0.30, LogLik = 27.63, Weight = 0.44, Figure 5, Table 5).

$$log_{10}(Marine\ Survival) = -0.77 + 4.18 * 10^{-10}hpc + 0.07pdo + year + \varepsilon$$

In addition to having the lowest AICc, no other model had a *Δ*AICc less than 2, thus strengthening its support as the best model. The random effect of year showed no trends (R^2 Marginal = 0.29, R^2 Conditional = 0.91).

4 - Discussion

This study highlighted the influence of creek flow on freshwater survival, highlighted possible impacts of freshwater growth on survival, and showed the impact of hatchery releases and PDO on marine survival. Scale growth analysis did not indicate freshwater or first year marine growth greatly affected Creek Coho Salmon marine survival, although there was some support for a negative relationship between freshwater year 2 growth and marine survival. Marine survival was positively related to hatchery pink and chum salmon production and PDO. These relationships, given current changes in climate and potential changes in hatchery production, reveal large potential impacts on Coho Salmon marine survival.

Of the variables we analyzed, creek flow during the spring of emergence from the gravel has the strongest effect on Auke Creek Coho smolt/adult production.). At high levels of Auke Creek flows, smolt/adult production is reduced. At these high levels of flow, debris and gravel movement can scour redds, although low flows can lead to dewatering of redds and degradation of rearing habitat (Mathews and Olson 1980; Lawson et al. 2004). The observed relationship suggests that scouring or increased flows may force juvenile Coho Salmon from optimal habitat before they are developmentally ready (Giannico and Healey 1998). Additionally, increased flow leads to increased turbidity, which reduces feeding success under experimental conditions (Berg and Northcote 1985). With shifts in watersheds in Southeast Alaska, and more specifically, Auke Creek's shift to a rain-dominated system from a historically snowmelt-driven system, we can expect to see increases in early, episodic high flow events (Shanley et al. 2015; Vulstek and Russell 2017). This might reduce smolt/adult production in the future.

The analysis of scale growth zones yielded inconclusive results. This highlights an important limitation of most scale studies, which is that we can analyze the scales of only the survivors that successfully returned to Auke Creek. Under the critical size, critical period hypothesis, we would expect that these surviving fish grew faster in their juvenile life stage than those that died as juveniles (Beamish and Mahnken 2001). This would result in a large, but relatively invariant set of survivors, which would limit our likelihood of detecting a correlation between size and survival. Similar results and conclusions have been drawn in previous studies of Auke Creek Coho Salmon scales (Robins 2006). However, more recent studies have shown that the effect of the critical size, critical period hypothesis may not be as strong as previously thought (Beacham et al. 2017, 2018). We found low variation in mean growth zones across the time series, possibly indicating consistent size selectivity (Marco-Ruis et al. 2012). However, with the inconclusive results we found, it is not possible to point to a specific cause of this low variation in growth, which highlights the need for future research. Due to the infrastructure of the Auke Creek Weir, it is possible to sample outmigrant Coho Salmon in their juvenile stage and thus a juvenile scale catalog has been maintained at Auke Creek since 1980. In future studies, it would be wise to explore possible differences in juvenile growth using Auke Creek juvenile scale data, as there are differing effects on marine survival that are occurring in the early marine critical-period and are difficult to capture in returning adult scales (Beamish and Mahnken 2001).

The results of the analysis provide valuable insight into the changes in Coho Salmon marine survival in Auke Creek. While there are no significant trends in marine survival over the entirety of the time series, substantial variation is observed, as well as a significant decline in marine survival over the last 15 years, indicate varying factors that have an effect on marine survival. Understanding the drivers of this irregular variation in survival over time is important and if we can find what influences this variation, it will allow for better management in the future.

In the recent history of Auke Creek, four studies have explored Coho Salmon marine survival, with the most recent using data through 2005 (Malick et al. 2009). Juvenile size, migration timing, hatchery releases, and the North Pacific Index were the strongest predictors of marine survival (Lum 2003; Briscoe et al. 2005; Robins 2006; Malick et al. 2009). With the additional years of Coho Salmon return data, we extended the time series and reexamined survival patterns. We observed that the strongest predictor model for marine survival includes a positive relationship with hatchery releases and PDO.

The positive effect that Chum and Pink Salmon hatchery releases have on marine survival has a few possible explanations. The first possible is that the hatchery-released fish provide a food resource for the migrating Coho Salmon. It has been shown that Coho Salmon are natural predators on juvenile Chum Salmon and Pink Salmon and that they can capture prey that is greater than half their own body length (Hargreaves and Lebrasseur 1985, 1986). Pink Salmon and Chum Salmon are an abundant food resource in the early marine environment of Auke Creek

Coho Salmon (Parker 1971; Landingham et al. 1998; Mortensen et al. 2000). This influence of an abundant food resource would likely be short-lived because Pink and Chum Salmon can grow faster than Coho Salmon and would quickly become large enough to avoid predation (Godin 1981).

The other possible longer and more likely effect that hatchery releases have upon Coho Salmon survival is that of a predation buffer (LaCroix et al. 2009). Hatchery releases and juvenile Coho Salmon inhabit the same area in the early marine period and the releases grow to be similar in size to the Coho Salmon, so hatchery releases can provide an alternate and more abundant food source for the predators of Coho Salmon (Parker 1971; Landingham et al. 1998; Mortensen et al. 2000; Briscoe et al. 2005; Orsi et al. 2013). This has been discussed as a regulator of salmon survival and hatchery releases were related to increased Coho Salmon marine survival in previous studies (Fisher and Pearcy 1988; Willette et al. 2001; Andres Araujo et al. 2013).

Over this extended time series, PDO and its region-specific effects showed a strong, positive relationship with survival. High PDO is linked to increased primary productivity in northern Southeast Alaska, which improves salmon productivity (Mantua et al. 1997). However, this relationship is likely to continue only to a certain extent. High PDO is related to reductions in early marine survival and with climate change impacts, extreme ocean temperatures will lead to reduced primary productivity and shifts in prey assemblages (Mantua et al. 1997; Shanley et al. 2015). The non-significance of the other physical factors, such as creek temperature, might be explained by their having stronger effects in specific years as opposed to having consistent effects over the entire time series (Malick et al. 2009). Thus the contribution of physical factors, while not strong, cannot be completely ignored.

It is worth noting that juvenile size did not contribute greatly to marine survival over the entire time series. This is uncommon as it has been shown that early growth has a strong influence on survival (Holtby et al. 1990; Sogard 1997; Beamish and Mahnken 2001). The absence of juvenile size in the best-supported models could be because size may be a more important factor in determining survival during years of poor growing conditions and low food abundance (Holtby et al. 1990; Cooney et al. 2001). Additionally, little variation was seen over the time series in juvenile length and it is possible that this reduced variation in length reflects stable selection on smolt size.

In summary, the analysis indicates that creek flow has the largest impact on Auke Creek Coho Salmon smolt/adult production and that the considerable variation in marine survival can be best explained by the abundance of hatchery released fish in the region and PDO. Using this information, we can help ensure the successful management and continued sustainable harvest for future generations of a species that is of significant sport, commercial, and traditional value to Southeast Alaska.

5 - References

Andres Araujo, H., Holt, C., Curtis, J.M., Perry, R.I., Irvine, J.R., and Michielsens, C.G. 2013. Building an ecosystem model using mismatched and fragmented data: A probabilistic network of early marine survival for Coho Salmon *Oncorhynchus kisutch* in the Strait of Georgia. Prog. Oceanogr. **115**: 41–52. doi:10.1016/j.pocean.2013.05.022.

Beacham, T.D., Andres Araujo, H., Tucker, S., and Trudel, M. 2018. Validity of inferring size-selective mortality and a critical size limit in pacific salmon from scale circulus spacing. PLoS ONE **13**: e0199418. doi:10.1371/journal.pone.0199418.

Beacham, T.D., Neville, C.M., Tucker, S., and Trudel, M. 2017. Is there evidence for biologically significant size-selective mortality of Coho Salmon during the first winter of marine residence? Trans. Am. Fish. Soc. **146**: 395–407. Taylor & Francis. doi:10.1080/00028487.2017.1285349.

Beamish, R.J., and Mahnken, C. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. . Prog. Oceanogr. **49**: 423–437. doi:10.1016/S0079-6611(01)00034-9.

Beamish, R.J., Mahnken, C., and Neville, C.M. 2004. Evidence that reduced early marine growth is associated with lower marine survival of Coho Salmon. Trans. Am. Fish. Soc. **133**: 26–33. doi:10.1577/T03-028.

Beier, C.M., Patterson, T.M., and Chapin, F.S. 2008. Ecosystem services and emergent vulnerability in managed ecosystems: A geospatial decision-support tool. Ecosystems **11**: 923–938. doi:10.1007/s10021-008-9170-z.

Bell, D., Kovach, R.P., Vulstek, S.C., Joyce, J.E., and Tallmon, D.A. 2017. Climate-induced trends in predator-prey synchrony differ across life-history stages for an anadromous salmonid. Can. J. Fish. Aquat. Sci. **74**: 1431–1438.

Berg, L., and Northcote, T. 1985. Changes in territorial, gill-flaring, and feeding behavior in juvenile Coho Salmon (*Oncorhynchus kisutch*) following short-term pulses of suspended sediment. Can. J. Fish. Aquat. Sci. **42:** 1410-1417.

Bernard, D.R., and Clark, J.E. 1996. Estimating salmon harvest with coded-wire tags. Can. J. Fish. Aquat. Sci. **53**: 2323–2332. doi:10.1139/f96-182.

Briscoe, R.J., Adkison, M.D., Wertheimer, A.C., and Taylor, S.G. 2005. Biophysical factors associated with the marine survival of Auke Creek, Alaska, Coho Salmon. Trans. Am. Fish. Soc. **134**: 817–828. doi:10.1577/T04-063.1.

Cooney, R.T., Allen, J.R., Bishop, M.A, Eslinger, D.L., Kline, T., Norcross, B.L., McRoy, C.P., Milton, J., Olsen, J., Patrick, V., Paul, A ., Salmon, D., Scheel, D., Thomas, G.L., Vaughan, S.L., and Willette, T.M. 2001. Ecosystem control of Pink Salmon (*Oncorhynchus gorbuscha*) and Pacific herring (*Clupea pallasi*) populations in Prince William Sound, Alaska. Fisheries Oceanography **10**: 1–13. doi:10.1046/j.1054-6006.2001.00039.x.

Di Lorenzo, E., Schneider, N., Cobb, K.M., Franks, P.J., Chhak, K., Miller, A.J., McWilliams, J.C., Bograd, S.J., Arango, H., Curchitser, E., Powell, T.M., and Rivière, P. 2008. North Pacific Gyre Oscillation links ocean climate and ecosystem change. Geophysical Research Letters **35**: 2–7. doi:10.1029/2007GL032838.

Fall, J.A., Braem, N.M., Brown, C.L., Evans, S.H., Hutchinson-Scarbrough, L., Ikuta, H., Jones, B., La Vine, R., Lemons, T., Marchioni, M.A., Mikow, E., Ream, J.T., and Sill, L.A. 2014. Alaska subsistence and personal use salmon fisheries 2012 annual report. Alaska Department of Fish and Game (Technical Paper No. 406). Anchorage, Alaska

Farley, E.V., Murphy, J.M., Adkison, M.D., Eisner, L.B., Helle, J.H., Moss, J.H., and Nielsen, J. 2007. Early marine growth in relation to marine-stage survival rates for Alaska Sockeye Salmon (*Oncorhynchus nerka*). Fishery Bulletin **105**: 121–130.

Fisher, J., and Pearcy, W. 1988. Growth of juvenile coho salmon (*Oncorhynchus kisutch*) off Oregon and Washington, USA, in years of differing coastal upwelling. Can. J. Fish. Aquat. Sci. **45**: 1036–1044.

Fisher, J.P., and Pearcy, W.G. 2005. Seasonal changes in growth of coho salmon (*Oncorhynchus kisutch*) off Oregon and Washington and concurrent changes in the spacing of scale circuli. Fishery Bulletin **103**: 34–51.

Fukuwaka, M., and Kaeriyama, M. 1997. Scale analyses to estimate somatic growth in Sockeye Salmon, *Oncorhynchus nerka*. Can. J. Fish. Aquat. Sci. **54**: 631–636. doi:10.1139/cjfas-54-3-631.

Giannico, G.R., and Healey, M.C. 1998. Effects of flow and food on winter movements of juvenile Coho Salmon. Trans. Am. Fish. Soc. **127**: 645–651. doi:10.1577/1548-8659(1998)127<0645.

Godin, J.G.J. 1981. Effect of hunger on the daily pattern of feeding rates in juvenile Pink Salmon, *Oncorhynchus gorbuscha* Walbaum. Journal of Fish Biology **19**: 63–71. doi:10.1111/j.1095-8649.1981.tb05811.x.

Graham, C. 2016. Evaluation of growth, survival, and recruitment of Chinook Salmon in Southeast Alaska rivers. M.S. thesis, University of Alaska Fairbanks.

Gross, M.R. 1991. Salmon breeding behavior and life history evolution in changing environments. Ecology **72**: 1180–1186.

Hagen, P.T., Oxman D.S., and Agler B.A. 2001. Developing and deploying a high resolution imaging approach for scale analysis. (NPAFC Doc. 567). 11 p. Mark, Tag, and Age Lab, Alaska Department of Fish and Game, P.O. Box 25526, Juneau, Alaska.

Hargreaves, N.B., and Lebrasseur, R.J. 1985. Species selective predation on juvenile Pink (*Oncorhynchus gorbuscha*) and Chum Salmon (*O. keta*) by Coho Salmon (*O. kisutch*). Can. J. Fish. Aquat. Sci. **42**: 659–668.

Hargreaves, N.B., and Lebrasseur, R.J. 1986. Size selectivity of Coho (*Oncorhynchus kistuch*) preying on juvenile Chum Salmon (*O. keta*). Can. J. Fish. Aquat. Sci. **43**: 581–586.

Holtby, L., Anderson, B.C., and Kadowaki, R.K. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of Coho Salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. **47**: 2181–2194.

Kovach, R.P., Joyce, J.E., Echave, J.D., Lindberg, M.S., and Tallmon, D.A. 2013. Earlier migration timing, decreasing phenotypic variation, and biocomplexity in multiple salmonid species. PLoS One **8**: e53807. doi:doi.org/10.1371/journal.pone.0053807.

Kovach, R.P., Joyce, J.E., Vulstek, S.C., Barrientos, E.M., and Tallmon, D.A. 2014. Variable effects of climate and density on the juvenile ecology of two salmonids in an Alaskan lake. Can. J. Fish. Aquat. Sci. **71**: 799–807. doi:10.1139/cjfas-2013-0577.

LaCroix, J.J., Wertheimer, A.C., Orsi, J.A., Sturdevant, M.V., Fergusson, E.A., and Bond, N.A. 2009. A top-down survival mechanism during early marine residency explains Coho Salmon year-class strength in southeast Alaska. Deep-Sea Research Part II: Topical Studies in Oceanography **56**: 2560–2569. doi:10.1016/j.dsr2.2009.03.006.

Landingham, J.H., Sturdevant, M.V., and Brodeur, R.D. 1998. Feeding habits of juvenile Pacific salmon in marine waters of southeastern Alaska and northern British Columbia. Fishery Bulletin **96**: 285–302.

Lawson, P.W., Logerwell, E.a., Mantua, N.J., Francis, R.C., and Agostini, V.N. 2004. Environmental factors influencing freshwater survival and smolt production in Pacific Northwest Coho Salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. **61**: 360–373. doi:10.1139/f04-003.

Lewis, B., Grant, W.S., Brenner, R.E., and Hamazaki, T. 2015. Changes in size and age of Chinook Salmon *Oncorhynchus tshawytscha* returning to Alaska. PLoS One **10**: e0130184. doi:10.1371/journal.pone.0130184.

Lum, J.L. 2003. Effects of smolt length and emigration timing on marine survival and age at maturity of wild Coho Salmon (*Oncorhynchus kisutch*) at Auke Creek, Juneau, Alaska. M.S. Thesis, University of Alaska Fairbanks.

Major, R.L., Mosher, K.H., and Mason, J.E. 1972. Identification of stocks of Pacific salmon by means of their scale features. U.S. Dep. Commer., NOAA Tech. Memo: 209–231.

Malick, M.J., Adkison, M.D., and Wertheimer, A.C. 2009. Variable effects of biological and environmental processes on Coho Salmon marine survival in southeast Alaska. Trans. Am. Fish. Soc. **138**: 846–860. doi:10.1577/T08-177.1.

Malick, M.J., Cox, S.P., Mueter, F.J., Dorner, B., and Peterman, R.M. 2016. Effects of the North Pacific Current on the productivity of 163 Pacific salmon stocks. Fisheries Oceanography **26**: 268–281. doi:10.1111/fog.12190.

Malick, M.J., Cox, S.P., Mueter, F.J., Peterman, R.M., and Bradford, M. 2015. Linking phytoplankton phenology to salmon productivity along a north–south gradient in the Northeast Pacific Ocean. Can. J. Fish. Aquat. Sci. **72**: 697–708. doi:10.1139/cjfas-2014-0298.

Mantua, N.J., Hare, S.R., Zhang, Y., Wallace, J.M., and Francis, R.C. 1997. A Pacific Interdecadal Climate Oscillation with impacts on salmon production. Bulletin of the American Meteorological Society **78**: 1069–1079. doi:10.1175/1520-0477(1997)078<1069:APICOW>2.0.CO;2.

Marco-Rius, F., Caballero, P., Morán, P., and Garcia de Leaniz, C. 2012. And the last shall be first: heterochrony and compensatory marine growth in sea trout (*Salmo trutta*). PLoS One 7: e45528. doi:10.1371/journal.pone.0045528.

Mathews, S.B., and Olson, F.W. 1980. Factors affecting Puget Sound Coho Salmon (*Oncorhynchus kisutch*) runs. Can. J. Fish. Aquat. Sci. **37**: 1373–1378.

Mortensen, D.G., Wertheimer, A.C., Taylor, S.G., and Landingham, J. 2000. The relation between early marine growth of Pink Salmon, *Oncorhynchus gorbuscha*, and marine water temperature, secondary production, and survival to adulthood. Fishery Bulletin **98**(: 319–335.

Mundy, P.R. 2005. The Gulf of Alaska: Biology and Oceanography. Alaska Sea Grant College Program: 214. doi:http://doi.org/10.4027/gabo.2005.

Nickelson, T.E. 1986. Influences of upwelling, ocean temperature, and smolt abundance on marine survival of Coho Salmon (*Oncorhynchus kisutch*) in the Oregon production area. Can. J. Fish. Aquat. Sci. **43**: 527–535. doi:10.1139/f86-063.

Orsi, J.A., Sturdevant, M.V., Fergusson, E.A., Heinl, S.C., Vulstek, S.C., and Joyce, J.E. 2013. Connecting the “dots” among coastal ocean metrics and Pacific salmon production in Southeast Alaska , 1997-2012. North Pacific Anadromous Fish Commission **9**: 260–266.

Parker, R.R. 1971. Size selective predation among juvenile salmonid fishes in a British-Columbia inlet. Journal of the Fisheries Research Board of Canada **28**: 1503–1510.

R Core Team. 2019. R: A language and environment for statistical computing. R: A language; environment for statistical computing, Vienna, Austria.

Robins, J.B. 2006. Biophysical factors associated with the marine growth and survival of Auke Creek, Alaska Coho Salmon. M.S. Thesis, University of Alaska Fairbanks.

Russell, J.R., Vulstek, S.C., Joyce, J.E., Kovach, R.P., and Tallmon, D.A. 2018. Long-term changes in length at maturity of Pacific salmon in Auke Creek Alaska. U.S. Dep. Commer., NOAA Tech. Memo. (NMFS-AFSC-384): 28.

Shanley, C.S., Pyare, S., Goldstein, M.I., Alaback, P.B., Albert, D.M., Beier, C.M., Brinkman, T.J., Edwards, R.T., Hood, E., MacKinnon, A., McPhee, M.V., Patterson, T.M., Suring, L.H., Tallmon, D.A., and Wipfli, M.S. 2015. Climate change implications in the northern coastal temperate rainforest of North America. Climatic Change **130**: 155–170. doi:10.1007/s10584-015-1355-9.

Shaul, L., Crabtree, K., Jones, E., McCurdy, S., and Elliott, B. 2011. Coho Salmon stock status and escapement goals in Southeast Alaska. Alaska Department of Fish and Game, Special Publication No. 11-21 **3**.

Smoker, W. 1955. Effects of stream flow on silver salmon production in western Washington: Seattle. Ph.D. thesis, University of Washington.

Sogard, S.M. 1997. Size-selective mortality in the juvenile stage of teleost fishes: a review. Bulletin of Marine Science **60**: 1129–1157.

Sparks, M.M., Falke, J.A., Quinn, T.P., Adkison, M.D., Schindler, D.E., Bartz, K., Young, D., and Westley, P.A. 2018. Influences of spawning timing, water temperature, and climatic warming on early life history phenology in western Alaska sockeye salmon. Can. J. Fish. Aquat. Sci. **76**: 123–135. doi:10.1139/cjfas-2017-0468.

Vulstek, S.C., and Russell, J.R. 2017. Watershed dynamics in the Auke Creek system, southeast Alaska. *In* Ecosystem Considerations 2017: Status of the Gulf of Alaska Marine Ecosystems (Gulf of Alaska Ecosystem Status Report). *Edited by* S. Zador and E. Yasumiishi. North Pacific Fishery Management Council, Anchorage, Alaska. pp. 53–55.

Willette, T.M., Cooney, R.T., Patrick, V., Mason, D.M., Thomas, G.L., and Scheel, D. 2001. Ecological processes influencing mortality of juvenile Pink Salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska. Fisheries Oceanography **10**: 14–41. doi:10.1046/j.1054-6006.2001.00043.x.

6 - Figures

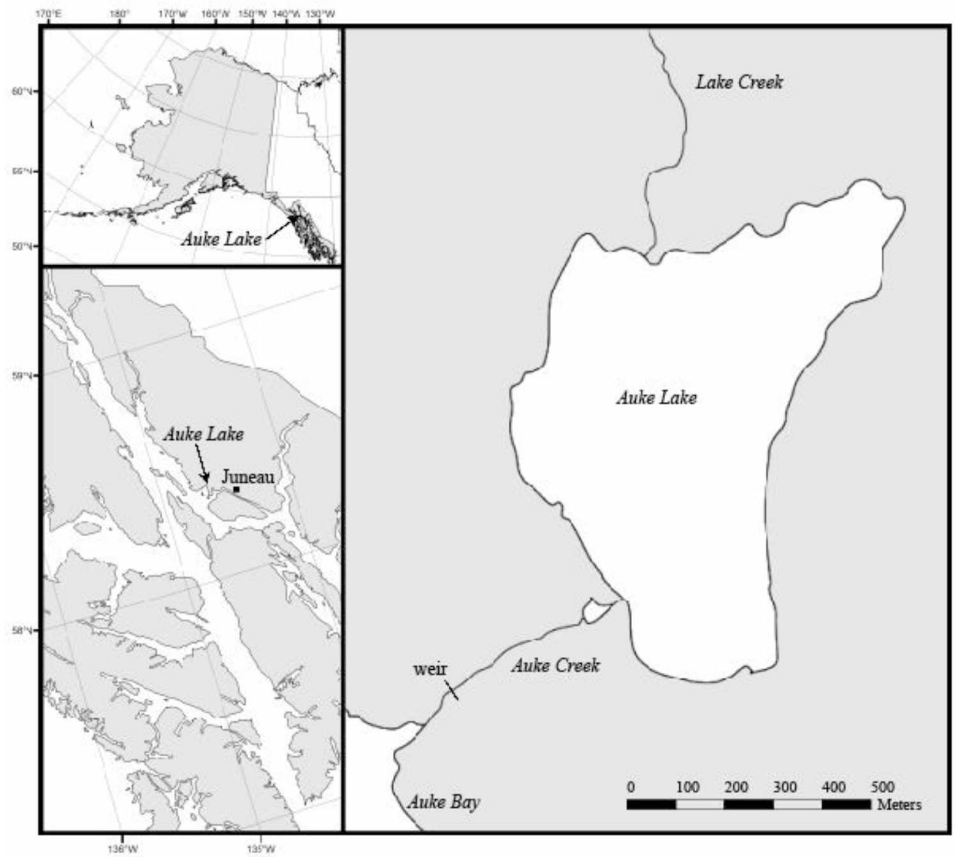

Figure 1 - Location of Auke Creek Research Station weir in the Auke Lake watershed in Southeast Alaska.

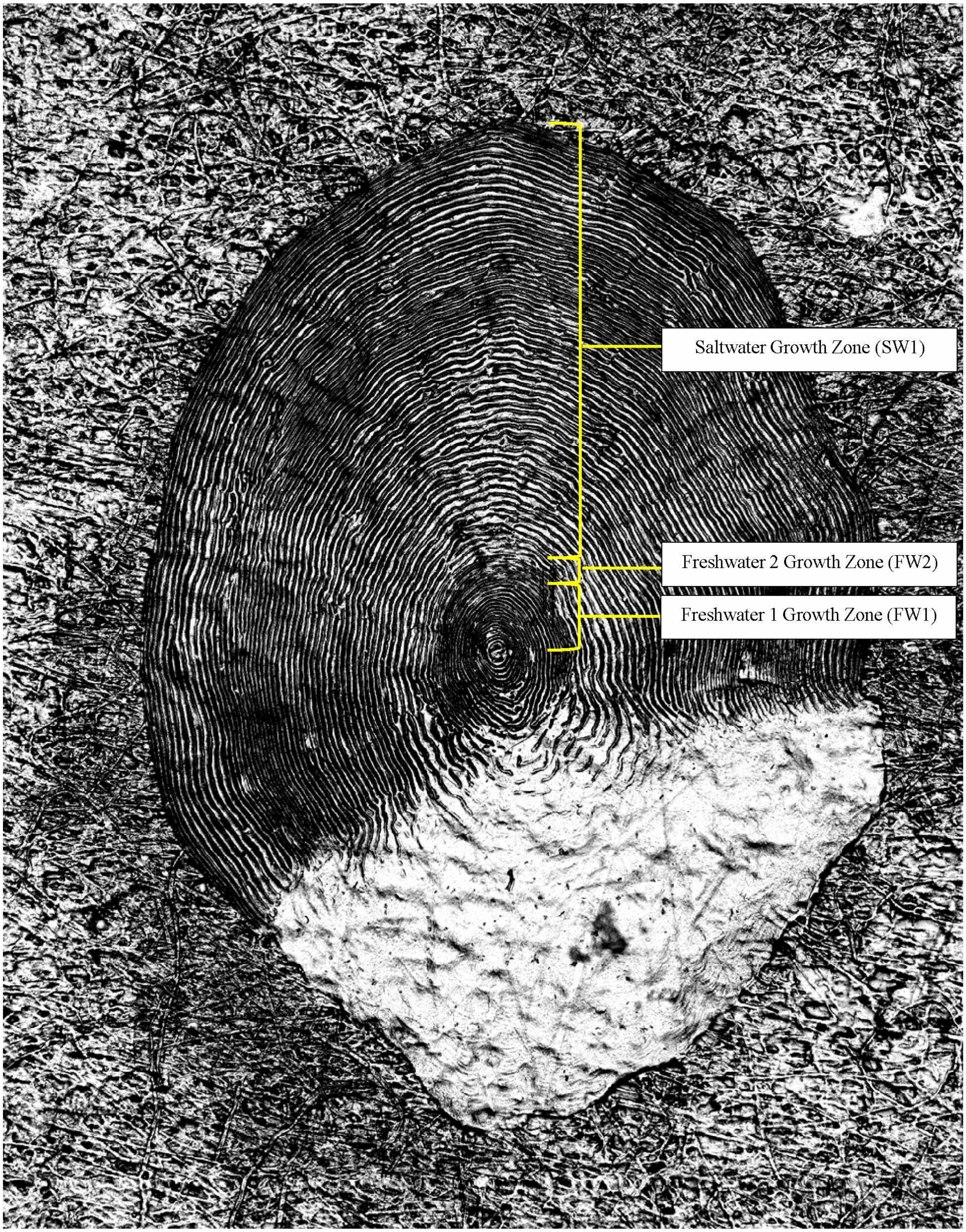

Figure 2 - Auke Creek Coho Salmon scale, age 2.1, annotated to show growth zones.

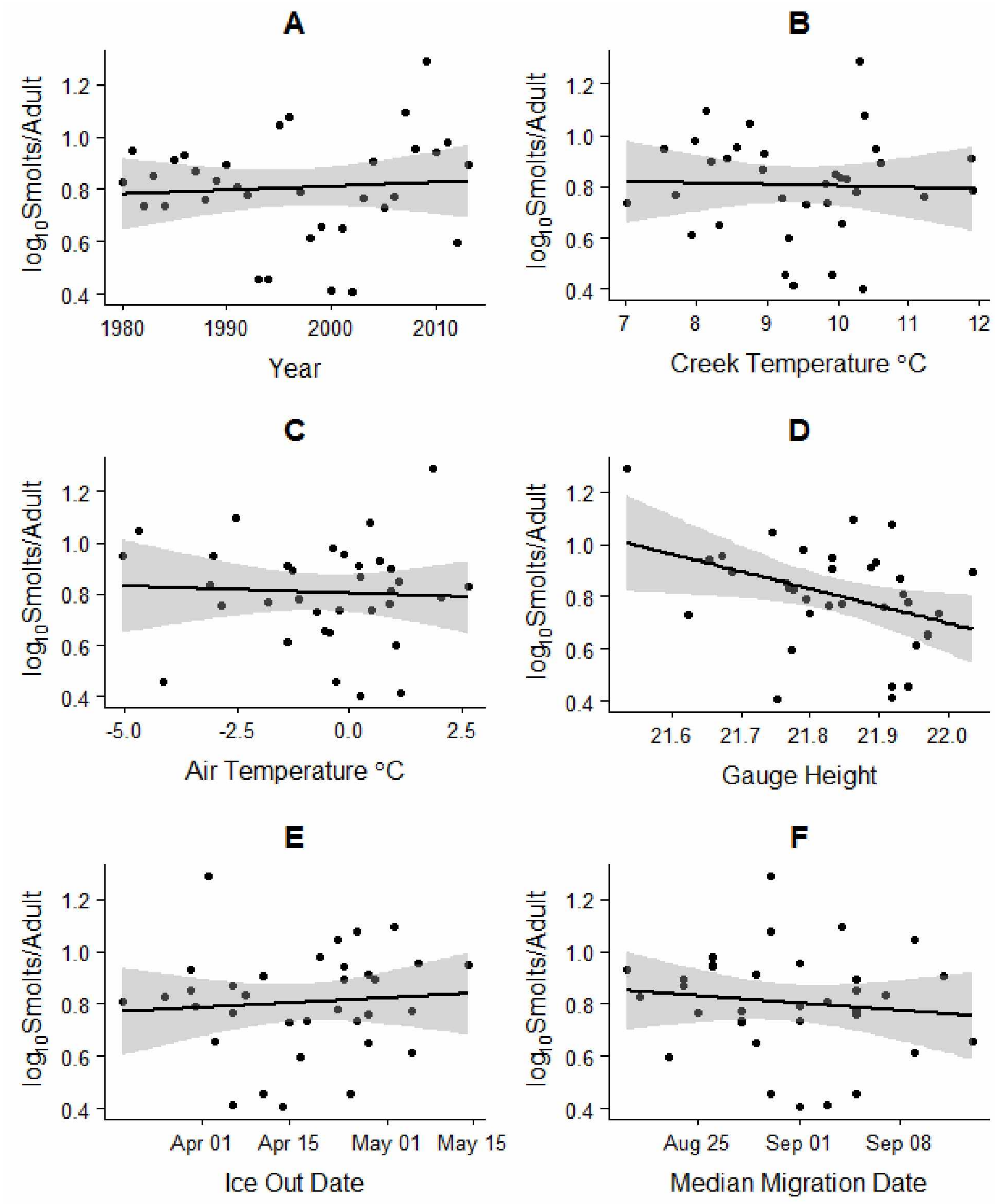

Figure 3 - Auke Creek Coho Salmon transformed smolts/adult production vs. all explanatory variables with linear trendline and 95% CI bands.

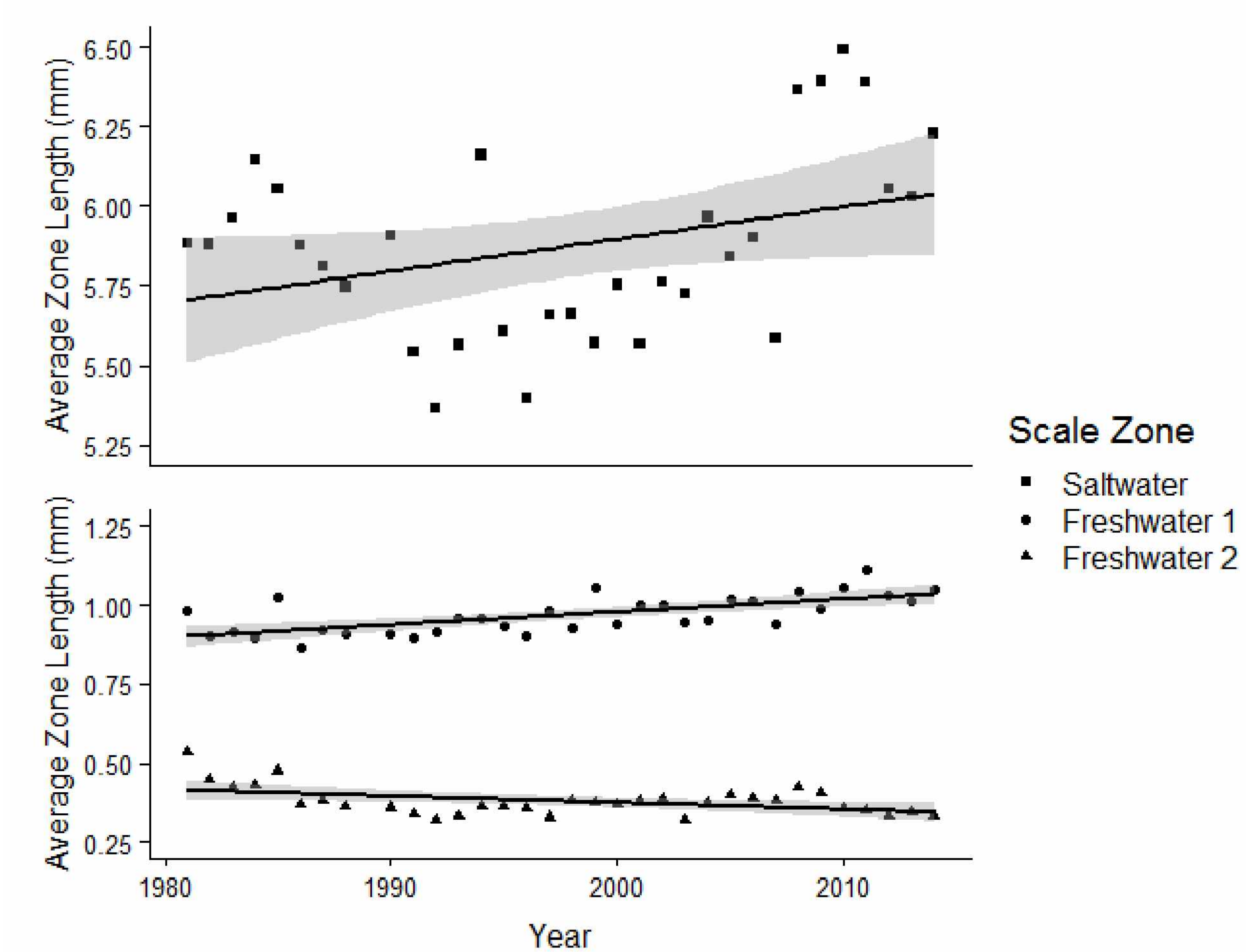

Figure 4 - Auke Creek Coho Salmon average interannuli zone length by year: 1981-2014, with linear trendline and 95% CI bands.

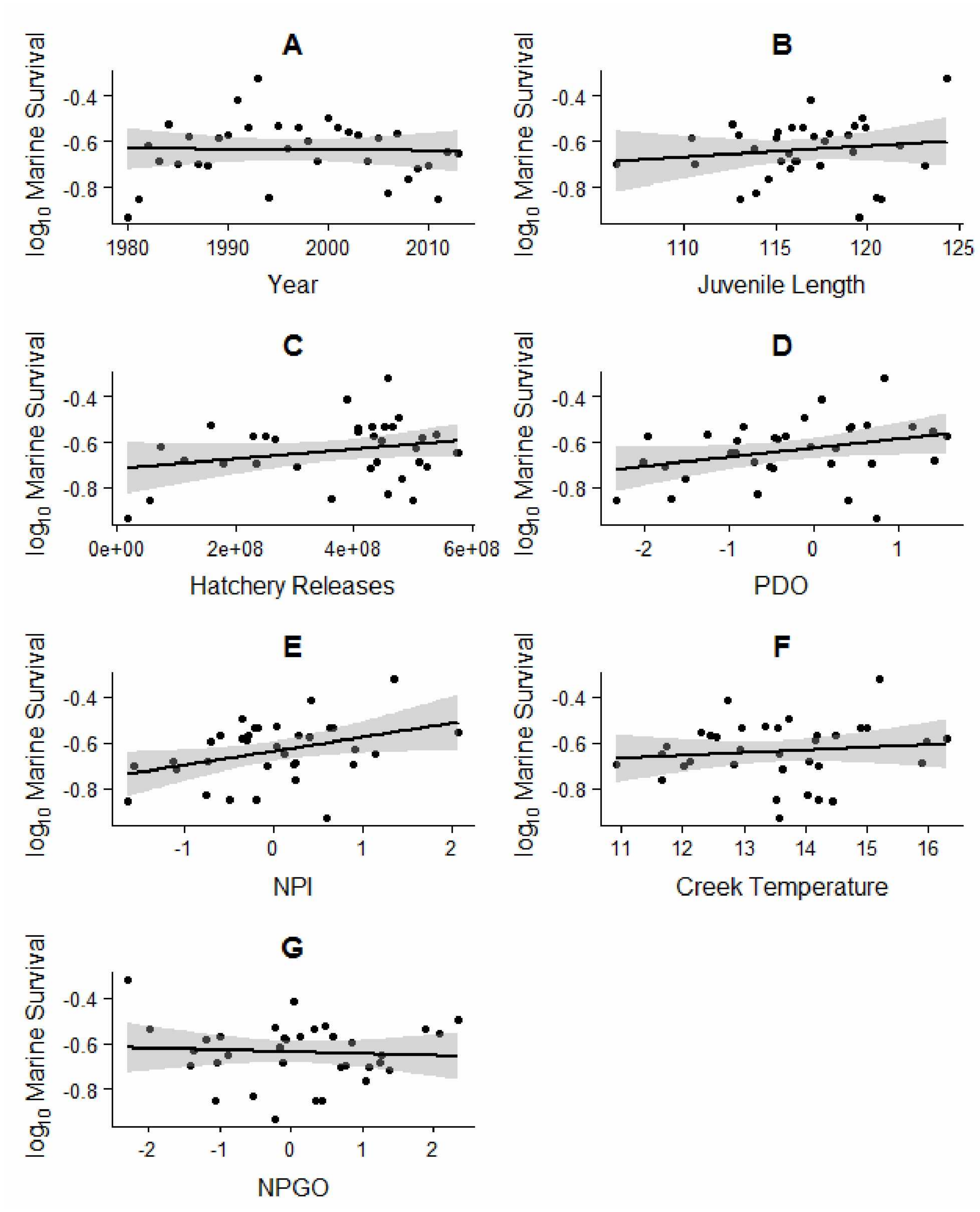

Figure 5 - Auke Creek Coho Salmon transformed marine survival vs. all explanatory variables with linear trendline and 95% CI bands.

7 - Tables

Table 1 - Variable names and descriptions for models of freshwater survival of Auke Creek Coho Salmon juveniles.

Variable Name	Description
SMOLT/ADULT	log10 transformed smolts produced per adult by brood year
CTEMP	Auke Creek temperature (Mar-Jul average)
ATEMP	Auke Bay air temperature (Jan-Mar average)
GAUGE	Auke Creek actual and modeled gauge height (April-Jun average)
ICEOUT	Annual ice-out date
MMD	Median migration date
YEAR (random effect)	Year of saltwater entry (1980 - 2013)

Table 2 - Variable names and descriptions for models of marine survival of Auke Creek Coho Salmon adults.

Variable Name	**Description**
MARINE SURVIVAL	log10 transformed marine survival by year of freshwater entry
JS.LENGTH	Weighted average length of age 1 and age 2 smolts
HPC	Avg hatchery Pink and Chum releases
PDO	Pacific Decadal Oscillation (Nov-Jan average)
NPI	North Pacific Index (Nov-Jan average)
CT	Creek temperature (May-July average
NPGO	North Pacific Gyre Oscillation (Nov-Jan average)
YEAR (random effect)	Year of saltwater entry (1980 - 2013)

Table 3 – Candidate models for freshwater survival analysis of smolts/adults vs. environmental conditions for Auke Creek Coho Salmon. Standard error of each parameter estimate is included in parentheses. See Table 1 for variable definitions.

Models	Intercept	Gauge	Iceout	MMD	R^2	DF	LogLik	AICc	ΔAICc	Weight
2	15.17 (6.126)	-0.658 (0.280)	-	-	0.15	4	9.83	-10.29	0.00	0.47
4	15.52 (6.180)	-0.683 (0.284)	0.00189 (0.002)	-	0.16	5	10.16	-8.18	2.11	0.16
6	15.14 (6.227)	-0.647 (0.295)	-	-0.000824 (0.006)	0.15	5	9.85	-7.55	2.74	0.12
1 (null)	0.8055 (0.034)	-	-	-	0.00	3	7.14	-7.47	2.82	0.12
5	1.777 (1.413)	-	-	-0.003992 (0.006)	0.01	4	7.39	-5.39	4.90	0.04
8	15.48 (6.285)	-0.672 (0.298)	0.00188 (0.002)	-0.000819 (0.006)	0.16	6	10.17	-5.24	5.05	0.04
3	0.6744 (0.279)	-	0.00122 (0.003)	-	0.01	4	7.26	-5.13	5.16	0.04
7	1.659 (1.450)	-	0.00127 (0.003)	-0.004072 (0.006)	0.02	5	7.52	-2.89	7.40	0.01

Table 4 – Candidate models scale growth analysis of marine survival vs. growth zones for Auke Creek Coho Salmon. Standard error of each parameter estimate is included in parentheses.

Models	Intercept	FW1	FW2	SW1	R^2	DF	LogLik	AICc	ΔAICc	Weight
3	-0.2746 (0.182)	-	-0.954 (0.479)	-	0.11	4	22.45	-35.48	0.00	0.38
1 (null)	-0.6359 (0.023)	-	-	-	0.00	3	20.47	-34.10	1.38	0.19
7	0.03 (0.460)	-	-0.864 (0.498)	-0.0576 (0.080)	0.13	5	22.74	-33.26	2.22	0.12
5	-0.09607 (0.469)	-	-	-0.0919 (0.080)	0.04	4	21.16	-32.89	2.59	0.10
4	-0.1443 (0.406)	-0.1357 (0.376)	-0.95 (0.454)	-	0.12	5	22.53	-32.83	2.65	0.10
2	-0.4916 (0.381)	-0.1489 (0.393)	-	-	0.00	4	20.54	-31.65	3.83	0.06
8	0.02697 (0.496)	0.00819 (0.446)	-0.863 (0.511)	-0.0585 (0.095)	0.13	6	22.74	-30.25	5.23	0.03
6	-0.1333 (0.502)	0.107 (0.456)	-	-0.1032 (0.094)	0.04	5	21.19	-30.16	5.32	0.03

Table 5 – Top 8 of 32 candidate models for marine survival analysis of marine survival vs. biological and environmental conditions for Auke Creek Coho Salmon. Standard error of each parameter estimate is included in parentheses. See Table 2 for variable definitions. Full table included in Appendix.

Models	Intercept	CT	HPC	JS.LEN	NPGO	NPI	PDO	R^2	DF	LogLik	AICc	ΔAICc	Weight
27	-0.774 (0.053)	-	4.18E-10 (<0.000)	-	-	-	0.0678 (0.021)	0.30	5	27.63	-43.11	0.00	0.44
31	-1.316 (0.613)	-	4.14E-10 (<0.000)	0.005 (0.005)	-	-	0.068 (0.021)	0.32	6	28.06	-41.02	2.09	0.16
28	-0.804 (0.206)	0.002 (0.016)	4.13E-10 (<0.000)	-	-	-	0.068 (0.021)	0.30	6	27.64	-40.17	2.94	0.10
17	-0.637 (0.021)	-	-	-	-	0.062 (0.027)	-	0.14	4	24.06	-38.74	4.37	0.05
19	-0.713 (0.054)	-	2.05E-10 (<0.000)	-	-	0.060 (0.026)	-	0.20	5	25.30	-38.46	4.65	0.04
32	-1.313 (0.627)	-0.001 (0.016)	4.15E-10 (<0.000)	0.005 (0.005)	-	-	0.068 (0.021)	0.32	7	28.07	-37.82	5.29	0.03
25	-0.627 (0.022)	-	-	-	-	-	0.040 (0.021)	0.10	4	23.30	-37.22	5.88	0.02
18	-0.858 (0.223)	0.016 (0.016)	-	-	-	0.065 (0.027)	-	0.17	5	24.60	-37.05	6.06	0.02

Appendix

Figure A1 - Random intercepts of year for the best supported model of freshwater survival Auke Creek Coho Salmon.

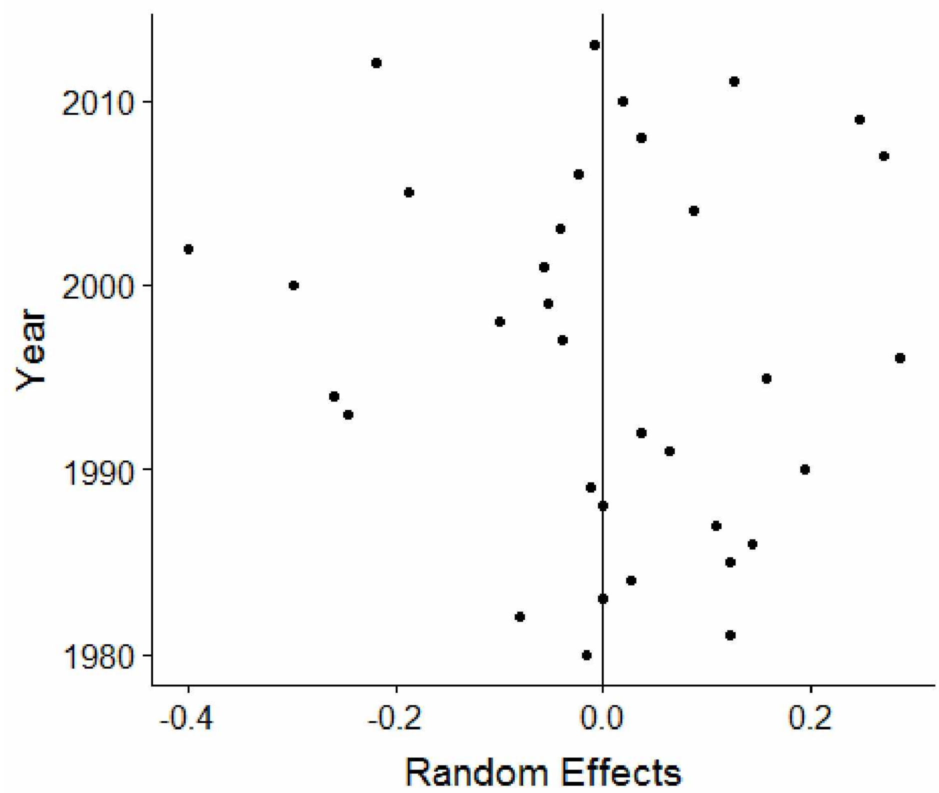

Figure A2 - Random intercepts of year for the scale growth model of Auke Creek Coho Salmon**.**

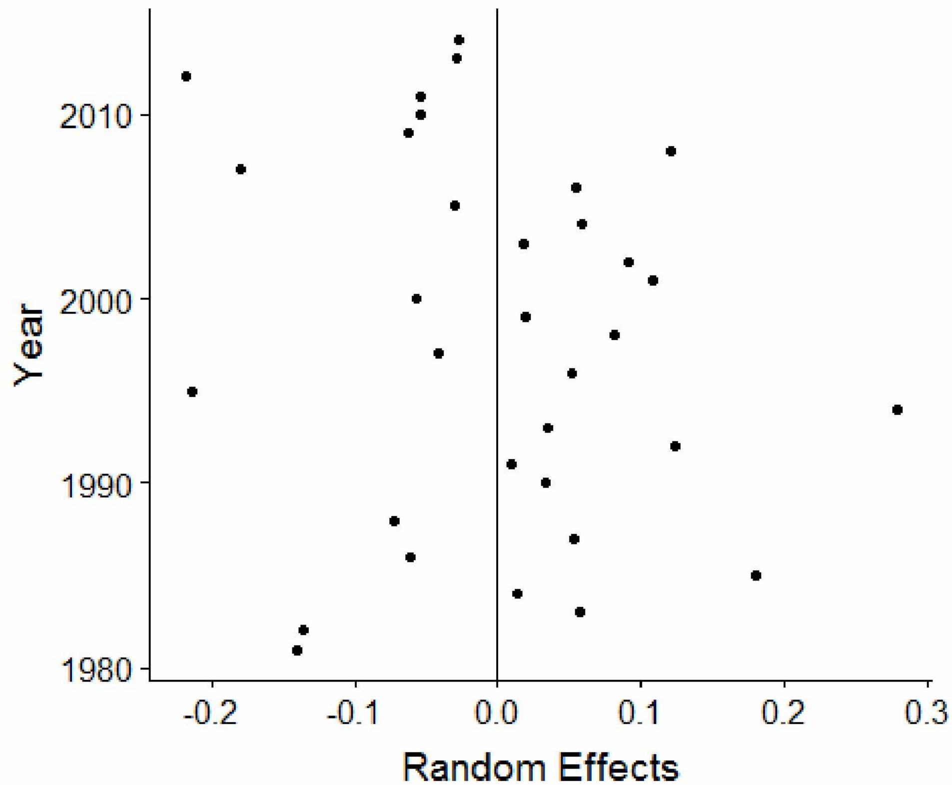

Figure A3 - Random intercepts of year for the best supported model of marine survival Auke Creek Coho Salmon.

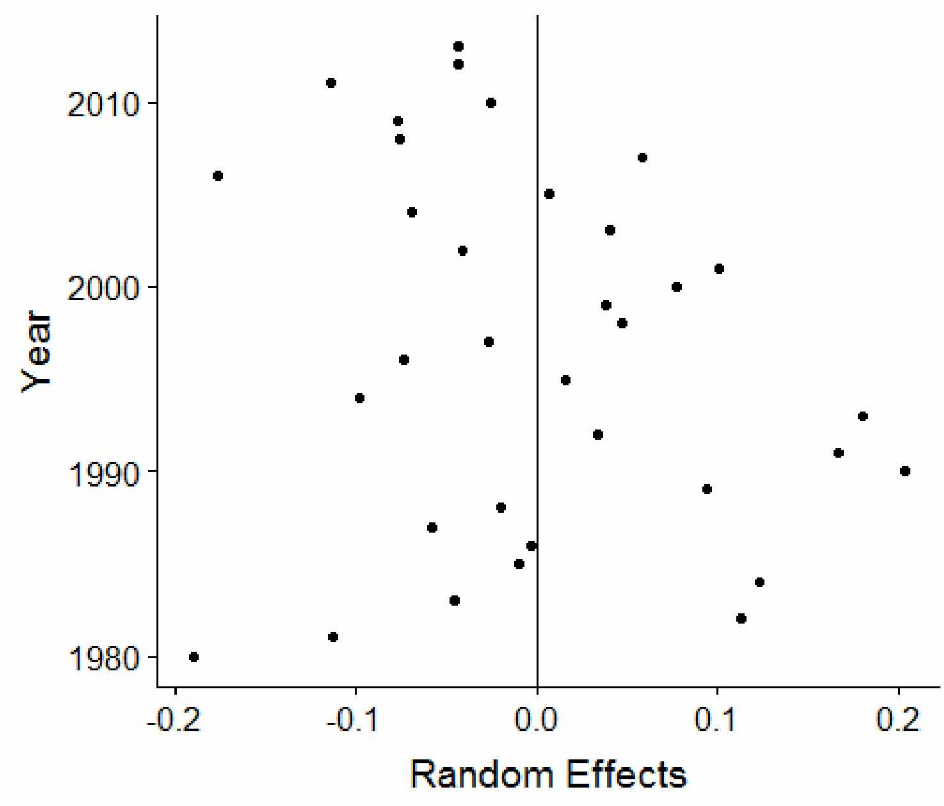

Table A1 – Candidate models for marine survival analysis of marine survival vs. biological and environmental conditions for Auke Creek Coho Salmon. See Table 2 for variable definitions.

Models	Intercept	CT	HPC	JS.LEN	NPGO	NPI	PDO	R^2	DF	LogLik	AICc	ΔAICc	Weight
27	-0.774	-	4.18E-10	-	-	-	0.068	0.30	5	27.63	-43.11	0.00	0.44
31	-1.316	-	4.14E-10	0.005	-	-	0.068	0.32	6	28.06	-41.02	2.09	0.16
28	-0.804	0.002	4.13E-10	-	-	-	0.068	0.30	6	27.64	-40.17	2.94	0.10
17	-0.637	-	-	-	-	0.062	-	0.14	4	24.06	-38.74	4.37	0.05
19	-0.713	-	2.05E-10	-	-	0.060	-	0.20	5	25.30	-38.46	4.65	0.04
32	-1.313	- 0.001	4.15E-10	0.005	-	-	0.068	0.32	7	28.07	-37.82	5.29	0.03
25	-0.627	-	-	-	-	-	0.040	0.10	4	23.30	-37.22	5.88	0.02
18	-0.858	0.016	-	-	-	0.065	-	0.17	5	24.60	-37.05	6.06	0.02
21	-1.192	-	-	0.005	-	0.062	-	0.16	5	24.43	-36.72	6.39	0.02
23	-1.217	-	1.99E-10	0.004	-	0.061	-	0.22	6	25.63	-36.16	6.95	0.01
1 (null)	-0.638	-	-	-	-	-	-	0.00	3	21.46	-36.11	6.99	0.01
20	-0.861	0.011	1.84E-10	-	-	0.063	-	0.22	6	25.57	-36.03	7.08	0.01
3	-0.717	-	2.13E-10	-	-	-	-	0.07	4	22.61	-35.84	7.26	0.01
29	-1.236	-	-	0.005	-	-	0.041	0.13	5	23.73	-35.32	7.79	0.01
26	-0.797	0.013	-	-	-	-	0.040	0.12	5	23.61	-35.07	8.04	0.01
22	-1.255	0.014	-	0.004	-	0.064	-	0.18	6	24.81	-34.52	8.59	0.01
5	-1.194	-	-	0.005	-	-	-	0.02	4	21.78	-34.18	8.93	0.01
2	-0.800	0.012	-	-	-	-	-	0.01	4	21.71	-34.03	9.07	0.00
9	-0.637	-	-	-	-0.008	-	-	0.00	4	21.54	-33.69	9.41	0.00
7	-1.220	-	2.08E-10	0.004	-	-	-	0.08	5	22.89	-33.64	9.47	0.00
11	-0.718	-	2.19E-10	-	-0.010	-	-	0.07	5	22.76	-33.38	9.73	0.00
24	-1.256	0.009	1.83E-10	0.004	-	0.062	-	0.23	7	25.80	-33.29	9.82	0.00
4	-0.805	0.007	2.01E-10	-	-	-	-	0.07	5	22.69	-33.24	9.87	0.00
30	-1.280	0.010	-	0.004	-	-	0.041	0.13	6	23.91	-32.71	10.40	0.00
6	-1.237	0.009	-	0.004	-	-	-	0.03	5	21.93	-31.71	11.40	0.00
13	-1.179	-	-	0.005	-0.007	-	-	0.02	5	21.84	-31.54	11.57	0.00
10	-0.786	0.011	-	-	-0.004	-	-	0.02	5	21.73	-31.31	11.80	0.00
15	-1.200	-	2.14E-10	0.004	-0.010	-	-	0.09	6	23.02	-30.93	12.18	0.00
8	-1.238	0.004	2.00E-10	0.004	-	-	-	0.08	6	22.92	-30.74	12.37	0.00
12	-0.773	0.004	2.11E-10	-	-0.009	-	-	0.08	6	22.79	-30.47	12.64	0.00
14	-1.223	0.008	-	0.004	-0.004	-	-	0.03	6	21.95	-28.78	14.32	0.00
16	-1.208	0.002	2.11E-10	0.004	-0.009	-	-	0.09	7	23.02	-27.74	15.37	0.00